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On Farm Conservation of Crop Genetic Resource: Declining *De Facto* Diversity and Optimal Funding Strategy

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Abstract

Crop genetic resources (CGRs) are crucial natural resource which ensure food or livelihood security of billions of people today as well as ensure future agricultural innovations. However, the CGR diversity remaining in *in situ*, particularly in subsistence farming is becoming extinct due to change in economic and technological development over time. An optimal funding strategy is required for conservation of these CGRs. In this paper, I have discussed an economic perspective on why and how the *de facto* crop genetic resources (CGRs) diversity declines with changing economic and environmental context. The model maximizes the net revenue from the farmers land allocation strategy to different CGRs under economic and technical constraints with linear demand and cost functions. Furthermore, the model suggests how to minimize the cost of *on farm* conservation of these crop genetic resources *in situ* (or *ex situ*) without forfeiting farmer's well-being in a changing perspective of economics and technology. The theoretical model developed in this study is employed to demonstrate the applicability for *on farm* conservation of rice genetic diversity in Nepal. The study suggests an optimal fund allocation strategy that minimizes the cost of conservation by (i) identifying particular CGRs (rice landraces) that are prone to extinct from the community and (ii) categorizing the farmers in the community having minimum cost of conservation for those particular landraces. As the model maximizes the farmers' revenues, it could ensure better livelihood of individuals in the community while minimizing the cost of *in situ* conservation of biodiversity on farm.

Keywords

Crop Genetic Resource, Conservation, Landraces, Cost Minimization, Nepal

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1. Introduction

Crop genetic diversity (agrobiodiversity), a subset of biodiversity, is simply defined as the diversity in crop genetic resources (CGRs) that are being cultivated by farming communities on their farm and the wild species that are potential for domestication [1]-[3]. These crop genetic resources are crucial natural resource which ensure food or livelihood security to billions of people today as well as future agricultural innovations [4] because such agricultural genetic resources possess many useful characteristics like resistancy to disease pest, high yield trait, stress tolerance [5] [6]. Much of the crop genetic diversity remaining *in situ*[1] today is found on the semi-subsistence farms[2] of poor countries and the small-scale farms of industrialized countries [10]-[14]. Such *de facto* conservation of biodiversity is mainly for risk aversion from the production environmental uncertainty [15] and partly because of sociocultural, environmental, and production heterogeneity such as soil type, irrigation availability [1] [16] [17].

Conservation of such genetic resource diversity is well recognized and international agreements such as Convention on Biological Diversity (CBD) and International Treaty on Plant Genetic Resources for Food and Agriculture (ITPGRFA) encourage the design of policies that convey economic incentives for farmers to conserve these important environmental assets *in situ*. *In situ* conservation approach is dynamic in nature allowing the genes to evolve and alter subjected to the exposed environment thus adding value over the *ex situ*[3] conservation. Hence, conservation of such CGRs *in situ* (on farm) is considered crucial over the *ex situ* (gene bank).

Large numbers of national and international agencies are employing many different strategies to conserve these resources *in situ* worldwide as suggested and promoted by the international treaties such as Convention on Biological Diversity (CBD) and United Nations Environment Program (UNEP). However, most of these conservation approaches consider some non-economic incentives to the farmers such as creating awareness through trainings and granting right to the farmers for conservation [2] [20] [21]. These strategies are myopic in nature and hardly consider the net revenue from the farming activities while implementing these conservation projects and programs. But there are empirical evidences that farmers are increasingly reluctant to provide this form of conservation [22], and that in the absence of counteracting policy [23], economic development (availability of modern varieties, risk abatement options) will further reduce the farmers' incentives to do so [24]. In short, *in situ* conservation (previously provided by individual farmers as a matter of choice, the *de facto* diversity) continues to decline on account of the development of agriculture worldwide [22] [25] [26]. Therefore, it can be argued that with the increasing food requirement, availability of the high yielding variety (HYV), risk abatement technology and increased access to income sources, farmers will replace the local diversity with HYV, thus losing whole biodiversity if the net revenue increases from the latter option.

This justifies that the well-considered argument for conservation should not only be based on ecological grounds but also on economic grounds [27] [28] because of the two reasons. First, the farming communities have to maintain their livelihoods through the use of the farm and its amenities (includes genetic materials); second, the financial resources for conservation programs are not sufficient to protect all genes and species [29].

Considering the threat of biodiversity extinction, a vast majority of studies have suggested a number of instruments for its conservation that provide economic incentives to the farmers both considering the financial limitations and farmers' economic losses. Pascual and Perrings [30] and UNEP [31] present detailed instruments for conservation of biodiversity. Some instruments include payment of ecosystems services (PES), the contracting out of conservation area, direct compensation, and tradable development rights etc. These instruments provide economic incentives to the farmers and promote conservation of biodiversity on farm. Of the many instruments suggested, compensation to the farmers for the foregone opportunity cost of growing HYV is one of the best economic instruments [31]-[33]. This instrument is not only simple to apply but also helps to measure the current diversity that maximize total productivity of the farm, helps to anticipate the possible risk of diversity loss due to changing economic and technological constraints and helps to minimize the cost of conservation.

In this paper a general model is suggested that predicts the farmers' land allocation for different crop varieties that maximize farm revenues under different economics and technological constraints and identifies the total lo-

[1]*In situ* conservation of agricultural biodiversity can be defined as the choice by farmers to continue managing crop genetic resources in their communities, in the agro-ecosystems, where they have evolved historically through processes of human and natural selection [7] [8].

[2]While there is no universal definition [9], we consider subsistence farming or semi-subsistence farming as a self-sufficiency farming in which the farmers focus on growing enough food to feed themselves and their families.

[3]*Ex situ* conservation involves conservation of CGRs components outside their natural habitats, *i.e.* off-farm, generally in gene banks [18]. Conservation at *ex situ* is static in nature and do not allow for evolutionary process [19].

cal CGR/landraces[4] or genes that are required to be compensated. Since *in situ* conservation is not a sector-wide phenomenon, it should be focused on the key regions that contain maximum diversity. Noting this fact, the theoretical model is employed to demonstrate the applicability of the model for *on farm* conservation of rice genetic diversity in Nepal. The study suggests an optimal fund allocation strategy that minimizes the cost of conservation by (i) identifying particular CGRs (rice landraces) that are prone to extinct from the community and (ii) categorizing the farmers in the community having minimum cost of conservation for those particular landraces. As the model maximizes the farmers' revenues, it could ensure better livelihood of individuals in the community while minimizing the cost of *in situ* conservation of biodiversity on farm.

2. The Model

Farmers have preferences of either diversifying the farm by growing multiple crops or varieties or growing few crops or sometime even a single crop or single variety. While allocating land to different varieties of a crop, farmers take into account the vectors of production cost and the productivity which depends on the characteristics of land, characteristics of crop varieties, or the possible risk measure options availability [15]. They also take into account of market price determined by culinary characteristics, and other sociocultural characteristics of the varieties [2] [38]. Since, different crop varieties respond differently to environmental or market risks, risk-averse farmers may choose to control their risk exposure through diversification [15] [39] [40].

Let π represents the farmers' revenue that depends on the choice of crop varieties, *N*. It consists of land allocation decision and vector of technical inputs (such as fertilizers, pesticides, labor, etc.). Farm land allocation x, is determinant of on farm biodiversity. Therefore, the farm land allocation *x* is decision variable that determines the *on farm* diversity and in turn total crop genetic diversity in the community. Let *M* be a given community, where $j = 1:m$ are the farmers in that community and *N* with $i = 1:n$, be total crop varieties (modern and local landraces) within the community. Farming communities want to maximize their revenue (profits) from their farmland given the level of crop genetic diversity, assuming that the input vectors (costs), the productivity, and the market price of the variety/landraces are known to all the farmers in the community.

Based on the profit maximizing theory (where "utility" is the sole function of profit), the overall objective function can then be formulated as a linear programing (LP) problem [41]:

$$Max\ \pi = \sum_{i=1}^{n}\sum_{j=1}^{m} y_{ij} p_i x_{ij} - \sum_{i=1}^{n}\sum_{j=1}^{m} c_{ij} x_{ij} \tag{*}$$

Subject to resources constraints:

$$\sum_{i=1}^{n} x_{ij} = b_j, \forall j \tag{1}$$

$$\sum_{i=1}^{n} c_{ij} x_{ij} = \eta_j, \forall j \tag{2}$$

$$x_{ij} \le S_{ij}, \forall i, j \tag{3}$$

and non-negativity constraints:

$y_{ij} \ge 0$; $c_{ij} \ge 0$; $s_{ij} \ge 0$; $p_i \ge 0$; $x_{ij} \ge 0$; $b_j \ge 0$; $\eta_j \ge 0$;

where,

x_{ij} is the decision variable, land allocated for landrace/variety *i* by farmer *j*;
y_{ij} is yield of landrace/variety *i* in farmland of farmer *j*;
c_{ij} is per unit cost of production of landrace/variety *i* in farmland of farmer *j*;
s_{ij} is land quality suitable for landrace/variety *i* in farmland of farmer *j*;
p_i is market price of landrace/variety *i*;
b_j is the land availability for farmer *j*;

[4]Landraces are local crop varieties with a high capacity to tolerate biotic and abiotic stresses resulting in high yield stability and an intermediate yield level under a low input agricultural system [34]. These are often highly variable in appearance, but they are each identifiable and usually have local names. The genetic variation within the landrace may be considerable but is far from random [35] [36]. Being heterogeneous, landraces do not meet the criteria for distinct, uniform and stable (DUS) characteristics that are required to be defined as modern varieties [37].

η_j is the budget limit for farmer *j*.

Equation (*) maximizes total farm revenue in the community which in-turn maximizes the individual farmers' benefits. Equations (1)-(3) are farmers' resource constraints. Constraint (1) is total land available to the farmers to grow different varieties of crop. The land resource is finite, given that no conversion of natural land into cultivation is allowed which is a very reasonable assumption. Constraint (2) is an economic constraint or budget constraint. This is the total expendable budget farmer can use in purchasing input vectors for different crop varieties. Since, different landraces/varieties require different costs for growing in different land parcels, farmers with enough income/budgets may choose to grow input intensive or high yielding variety(s), whereas farmers with smaller budget must choose low input varieties/landraces. Constraint (3) is environmental constraint that forces farmers to grow many different varieties in different land parcels. For instance, a farmer *j* can't allocate all his farmland to only a variety*i*because some land parcels are not suitable to grow that variety due to poor soil fertility, irrigation requirement, flooding, physical stress or similar reasons. Therefore, the farmer allocates such land to varieties that are resistant to these environmental stress and risk factors, thus diversifying land allocation to many landraces/varieties and increases the biodiversity. This plays very important role for conserving local genetic resources in diverse environment niches.

3. Application of the Models

To illustrate the model, I have taken data from 15 farmers from Kaski district of Nepal[5], where high genetic diversity exists. There are nine rice varieties, of which eight are local varieties/landraces (to be conserved) and one modern or high yielding variety. These different rice varieties have different cost of production, different productivity in different land parcels. The cost and production might vary among farmers based on the land type, for instance a good land parcel might need less cost and produce more while the poor parcel need much higher cost for same variety to produce same quantity or might not be suitable for that variety at all. The market price is different for different variety but usually do not depend on the production (fixed demand), particularly in such subsistence farming systems. Farmers always have finite cultivable land resource, finite budget for purchasing input vectors and different categories of land parcels. Such information can be collected using the intensive data plot (IDP) method[6] which can minimize the asymmetry in information collection.

4. Results and Discussions

The model application results are divided in different cases to shed lights on the economics of *de facto* diversity, the anticipated economic reasons of declining diversity over time and strategies for conservation *on farm*.

4.1. Case 1: The *De facto* Biodiversity

The diversity conserved *on farm* at the current resource constraint level, without any attention of conservation is considered as the *de facto* diversity *on farm*. If each farmer maximizes their profit given their land constraints (1), budget constraints (2) and the land suitability constraint (3), the total crop land allocated to different crop landraces can be obtained. This is illustrated by employing the data set obtained from the rice farming community of Nepal. An application of the model clearly shows that the net revenue of the farmers in the community is maximized when the land is allocated different landraces. This leads to the conservation of all the rice landraces (**Table 1**) at the given economic and environmental constraints level. Although sufficiently large area is allocated to local landraces, the land allocation to modern variety (*Mansuli*) is much higher compared to the local varieties (**Table 2**). For example 123 *Ropani*[7] land is allocated *Mansuli* (HYV) compared to a maximum of 36

[5]The data set is chosen from a large data set for illustration and reduced to small number due to insufficient information because the data were collected for another research by the author. The data were collected using standard survey questionnaire at household level. The details of the data collection are discussed in Poudel and Johnsen [18]. However, I would like to reiterate that only 15 farmers information are used for the illustration of the applicability of the model in this study. The data set can be available from the authors upon request. This study area, in Kaski district of Nepal, is reported to be a hot spot in terms of crop diversity [42]. The major crop is rice (*Oryza sativa*). Almost all the farmers grow this crop for which the farmers are maintaining a large number of local landraces [42] [43] along with some improved high yielding varieties.

[6]IDP is participatory data collection method where both researchers and farmers involve directly and simultaneously during the period of collection [1] [44].

[7]*Ropani* is a local unit, where 20 *ropani* is equal to 1 hectare.

Table 1. Maximum revenue and maximum number of crop landraces in different constraining case scenarios.

Different Case	Maximum Revenue	Number of Landraces	Remarks
Case I	461,914	All (8)	Constraints 1, 2 and 3 active
Case IIa†	585,545	7	Constraints 1, 2 and 4 active
Case IIb††	653,600	6	Constraints 1, 5 and 6 active
Case IIc	679,451	4	Only constraints 1 active
Case III	664,388	All (8)	Constraints 1 and 7 active
Full constraints	461,203	All (8)	All constraints 1, 2, 3 and 7 active

†$\alpha = 0.25$, ††$\alpha = 0.25$, and $\beta = 0.25$.

Table 2. Land allocation (Ropani) for different varieties and landraces in the community in different constraining case scenarios.

Landrace	Case I	Case IIa	Case IIb	Case IIc	Case III
Ekle	26.91(3)‡	21.5(2)	22(2)	20(1)	20(1)
Gurdi	34(3)	0(0)	0(0)	0(0)	10(1)
Madese	36(2)	14(2)	0(0)	0(0)	10(1)
Jetho	17(4)	19.5(5)	23.5(6)	28.5(2)	10.5(2)
Anadi	13(2)	15.5(3)	10.66(3)	10(1)	10(1)
Pahele	13.17(3)	15.75(3)	10(1)	0(0)	10(2)
Bayarni	18(3)	14.5(4)	8.75(1)	19(1)	19(1)
Jarneli	4(1)	11.5(2)	3.625(1)	0(0)	10(1)
Mansuli	123(12)	173(14)	206(14)	208(10)	186(8)

‡Figures in parentheses are number of farmers cultivating landrace or variety.

Ropani for *Gurdi* landrace. The main reason for the cultivation of modern variety is a higher profit arising from it. However, the farmers cannot allocate their land to modern varieties because either their land is not suitable and/or it requires higher input levels. Furthermore, these farmers cannot buy insurance and therefore, they diversify the crop varieties as a natural insurance policy, that leads to high diversity, which strongly holds the claim by Meng [39] and Di Falco and Perrings [15]. This leads to a *de facto* conservation of crop genetic resources diversity *on farm*. This justifies that the present biodiversity in developing countries is due to the economic and the environmental constraints. Given the result, we can conclude that *the de facto conservation of biodiversity is governed by the economic and environmental constraints of the farmers, namely the budget constraint* (2) *and land suitability constraint* (3).

4.2. Case 2: Is the *De Facto* Diversity Declining?

Most of the crop genetic diversities are retained in the least developed countries where food deficit is a major problem [4] [10] [13]. Food security is the responsibility of the state [45]. The state's first and most important role is to ensure better livelihood and improve the welfare of farming communities through increased and efficient technological development. The governments of these poor countries need to deal with the problem of food deficiency through appropriate technological development such as by developing modern crop varieties, lowering risks and uncertainties through improved farming, or by generating employment in the country. Such possible economic and technological development could relax or even inactivate some of the above mentioned constraint because;

- *Access to cheaper inputs reduces the budget constraint*: Access to cheaper inputs such as fertilizers, irrigation system, and pesticides availability could be increased overtime due to technological improvement such as cheaper transportation cost and mechanization in farming system. This eases the access to inputs and require lower budget and hence farmers can grow input intensive modern varieties thus decreasing the local genetic diversity where otherwise they would have been growing low yielding local varieties.

- *Increased income reduces the budget constraint*: Due to the economic development of the nation, people's income could rise and so does the farmers investment capacity thus the budget constraint particularly in such subsistence farming can be relaxed in the future.
- *Cheaper credit market reduces the budget constraint*: The increased and easy access to credits for farming will reduce the budget constraint since farmer's can purchase the required inputs and grow input incentive varieties instead of growing low input local variety.
- *New modern variety available for different land type*: The government and the public breeding companies are continuously working to develop high yielding varieties (HYVs) that can be grown in the diverse niches. This means in the long term, many different high yielding varieties will be available for growing in all the niches of land parcels thus increasing farm productivity but replacing low yielding local varieties.
- *Access to cheaper insurance policy than natural insurance*: Currently, farmers are diversifying the farm to reduce loss from the epidemic and other natural factors. However, as long as cheap insurance options are available, they may keep growing high yielding uniform crop varieties on their farm, thus losing local crop diversity.

Given the possibility of constraints dynamics overtime, the farmers could maximize their farm revenue differently due to the change in their model constraints.

Case IIa: Suppose that due to the change in income or cheaper access to inputs, the farmers' real income is increased by α percent in the previous income and this will relax the budget constraint (3), which can simply be modified as:

$$\sum_{i=1}^{n} c_{ij} x_{ij} = \eta_j \left(1+\alpha\right), \forall j \tag{4}$$

Case IIb: Furthermore assume that due to economic and technological development, the subsistence farming could be changed into mechanization and the real income increased by 2α, a further relaxation in budget constraint. Let β percent of the previously unsuitable land can be converted into suitable for high yielding or the high quality variety due to the improvement of new varieties and improved irrigation and accessibility of fertilization. In this case, constraint (2) and constraint (3) can be modified as (4) and (5):

$$\sum_{i=1}^{n} c_{ij} x_{ij} = \eta_j \left(1+2\alpha\right), \forall j \tag{5}$$

$$x_{ij} \le S_{ij} \left(1+\beta\right), \forall i, j \tag{6}$$

Case IIc: Finally, assume that a further relaxation of budget constraints such as access to full insurance, access to new modern varieties of the crops, the only constraint to maximize the farm revenue is the availability of land, constraint (1) but not budget and land suitability constraints.

An application of the model to maximize the objective function (*) subjected to new sets of constraints, increases the farm revenue because the farmer could choose high yielding and good quality variety or landraces due to relaxed or inactive constraints. Availability of these options, the subsistence farmers replace the local existing varieties with HYVs thus causing a serious decline in *de facto* biodiversity.

Table 1 shows how the landraces in the community decrease due to the economic and technological change that helps in relaxation of the model constraints and increase the farm revenue due to change in crop varieties. If the farmers income increases or the input price decreases (apparently increase in real income), and suppose the budget constraint is relaxed *i.e.* budget is increased by α fraction, the net revenue from the farming increases while the number of local crop varieties will decreases (Case IIa). If the farmers' income further increases (budget is added up by 2α) and the farmers improve the land such that β fraction of land parcels can now be allocated for different high yielding, high quality varieties (the land suitability constraint is relaxed), the profit further increases, whereas, the number of crop varieties will be decreased by two (Case IIb). Furthermore, if both economic and environmental constraints are inactive, the revenue further increases while the number of crop varieties cultivated is reduced to four, thus clearly leading to a loss of genetic diversity from the community.

Table 2 shows the land allocation to different varieties and the number of farmers growing these varieties under different model constraint scenarios. The land allocated to local varieties is decreasing and finally no land will be allocated for four of the local landraces (for example, *Gurdi*, *Madhese*, *Pahele* and *Jarneli*) if the economic and environmental constraints are inactive in the model. All the farmers cultivate modern variety whenever the budget meets the cost requirement and land is suitable for this variety. It can also be seen that only four local varieties will remain in the community out of eight varieties if there is no budgetary and land suitability constraints in the long-run with economic and technical development.

Table 3 shows how the number of crop landraces or varieties decreases on individual's farm when there are no production constraints. Highest number of varieties is maintained by the farmers when all the production constraints are active (Case I), while the least in Case IIc where no economic and environmental constraints are active. Most of the farmers would be growing single variety to maximize the total revenue, if they have no production constraints. This is the characteristics of the mechanized and well developed farming system where the local genetic diversity has already been lost.

This predicts that whatsoever the other factors are, the major force that drives farmers in choosing crop varieties is gross socioeconomic incentives (net farm revenue) from the crop varieties also mentioned by Benin *et al.* [46], *i.e.* farmers maximize the benefits from the land allocations to the crops and varieties now and in the future. This suggests that modernization or industrialization of the farming system could narrow down the genetic diversity from the agricultural landscapes [47]. Now we can conclude that *the de facto biodiversity decreases with economic and technological development leading to an increase in the farm revenue in the long-run.*

4.3. Case 3: The Biodiversity Conservation

Coping with food insecurity and ensuring on-farm conservation of genetic resources is much more difficult and challenging issue. The intervention of the modern technology could not be halted because it is important to feed the increasing population of the world through increased agricultural productivity from the finite land resource [48]. The only instrument that can be used for conservation of these genetic resources on farm is to provide economic incentives to the farmers as a compensation for conservation. The conservation is achieved by enforcing a new constraint to cultivate these landraces on farm. For conservation of plant genetic resources *on farm*, requires a Minimum Viable Population (MVP) of that species because the size of a population planted by a farmer will affect the amount of genetic variation of the crop population over time [49]-[51]. The smaller the population, the more likely that genetic drift, inbreeding, loss of alleles, and stochastic events will affect the population [49] [52]-[54]. The population for conservation of such diversity depends on several factors such as the biological growth habit of species, the survivability and reproductive coefficient, the environmental niches and so on. Particularly for conservation of Crop Genetic Resources (CGRs) on farm, the genetic variability maintenance is most important along with other factors. Given the minimum viable population constraint, the problem can be specified as:

$$\sum_{j=1}^{m} x_{ij} = r_i, \ \forall i \tag{7}$$

where r_i is the land allocation requirement for landrace i to maintain MVP.

The constraint (7) required for dynamic variability on farm which can be maintained by allocating minimum farmland for a particular species. Suppose landrace i is required to be produced in the community of farmers j, the total land allocated for that variety should be at least r unit assuming that the government has the right to select and enforce any farmer in community to allocate land for the local variety.

Table 3. Number of varieties and landraces grown by individual farmers in different constraining case scenarios.

Farmers	F01	F02	F03	F04	F05	F06	F07	F08	F09	F10	F11	F12	F13	F14	F15
Case I	3	2	2	3	2	1	3	1	3	2	3	1	3	1	3
Case IIa	3	2	2	3	2	1	2	1	4	2	2	1	3	5	2
Case IIb	3	2	2	3	2	1	2	1	2	2	2	1	2	2	1
Case IIc	1	1	1	1	1	1	1	1	1	1	1	1	2	1	1
Case III	1	1	1	1	2	1	2	1	1	1	1	1	2	1	1

Due to the addition of the new constraints, where the conservation agency such as government implement a minimum viable population (MVP)[8] constraint, all of the landraces can be conserved in the community. However, due to the cultivation of low yielding local varieties, farmers' net revenue decreases (**Table 1**). This could affect the livelihoods of those farmers who are required to grow these varieties. This loss to farmers can be defined as the foregone opportunity cost. We can conclude that *the conservation of CGR diversity on farm is possible by enforcing a conservation constraint in the community. The landraces can be increased but in the cost of decreased welfare.*

5. Cost of Conservation and Optimal Allocation of Funds

Since the farmers possess property right over their farmland and government is responsible for the improvement of the farmers' livelihood, the forgone opportunity cost of those farmers who are enforced to grow these landraces should be compensated. The foregone opportunity cost is the difference in net revenue (net profit), before and after the enforcement of the constraints. This can be calculated as:

$$\text{Conservation Cost} = \pi_0 - \pi_c \tag{8}$$

where

π_0 is the total profit without MVP constraint (Case IIc),

π_c is the total profit with the MVP constraint (Case III).

This is the minimum cost for conservation of crop genetic diversity on farm. Furthermore, mankind simply cannot protect everything. An effort to conserve everything won't be the sustainable solution [60]. This requires choosing an optimal level to be conserved in order to maximize net revenue from the diversity and minimize cost of such conservation. Therefore it is important to identify those crop varieties/species that are superior (low cost, high yielding or high priced) over the new modern varieties and are usually preferred by the farmers. The model presented above can identify the farmers in the community having minimum cost of conservation along with crop landraces that has least cost among all. A landrace that requires minimum cost of conservation should be selected for compensation, followed by second landrace and so on until entire budget allocated is spent. Landraces those require higher cost of conservation should be considered for other options of conservation such as *ex situ* or allele conservation.

By the application of the selected model in this particular example, out of the fifteen farmers studied only four farmers are required to be enforced for growing landraces for conservation, given the current availability of single modern variety in the community. However, due to the cultivation of these landraces there is a reduction in net revenue of the farmers which is the foregone opportunity cost or the conservation costs for these landraces. The cost of conservation of crop landraces in the community are calculated using Equation (8) and the total cost is NRs 15063. Individual cost of conservation varies among landraces and farmers (**Table 4**). Of the four farmers, the highest cost is incurred by "Farmer 06" who is growing *Jarneli* landrace, while the cost of growing *Madhese* landrace is least. Based on this opportunity cost of growing these landraces, the conservation fund should be allocated to conserve *Madhese*, *Pahele*, *Gurdi* and *Jarneli* landraces on the least cost priority. The remaining four landraces are either highly productive or they are better quality compared to the new available modern variety. These local landraces will be grown by the farmers in the community whatever the economic and environmental constraints are. This model can be useful to identify the crop landraces that are required to compensate and suggests efficient compensation mechanism.

The compensation cost is much lower and efficient as compared to a lump sum compensation that otherwise required to pay for all the eight landraces in the community. Furthermore, in case of limitation of funds for conservation, this model deals on the prioritization of the landraces to be conserved on farm. For instance in this particular example, if our conservation fund is NRs 10000, the policy maker can easily make decision to avoid on farm conservation of the *Jarneli* landrace (**Table 4**) and find alternative conservation approach such as *ex situ*

[8]Although no specific study about the requirement of minimum viable population (MVP) for rice (*Oryza Sativa*) is available, a rough estimation can be made based on Traill *et al.* [55]. Given the planting density of rice, it can be estimated that cultivation in 250 m^2 area contains around 5000 plants which is the minimum viable population for most of the monocotyledons species. Furthermore, *in situ* conservation of self-pollinated crops such as rice, MVP and inbreeding depression may not be more relevant [56], rather it requires to preserve the process of crop evolution via natural hybridization with wild and other varieties, natural selection, genetic drift. This demands large amount of cultivation area and diverse environment within the community where it is to be conserved. Many findings [1] [57]-[59] suggest that 0.25 to 0.5 ha farmland is required for maintenance of minimum population for rice to create the genetic variability and natural evolution overtime for conservation of a rice landrace in the community. Therefore, I have chosen a value of 0.5 ha in this illustration.

Table 4. Farmer and landraces having the highest cost of conservation.

Farmers	Landraces (area)	Conservation costs (NRs)
F04	Gurdi (10)	3275
F06	Jarneli (10), Pahele (2)	8268
F05	Pahele (8)	1760
F11	Madhese (10)	1760
Total	All	15,063

conservation. From the illustrations, we can conclude that *the cost of conservation can be minimized through the identification of the landraces and the farmers that have minimum cost of cultivation.*

6. Concluding Remarks

This study suggests the *de facto* of crop genetic diversity in subsistence farming is governed by the economic and environmental constraints of the farmers in the community. It shows that farmers have both economic and environmental constraints for maximization of their net revenue from farming activities. Their choice on crop biodiversity would be to maximize net revenue from allocation of land resources to these diverse varieties and landraces given such constraints. This leads to a *de facto* conservation of biodiversity on farm particularly in developing countries and subsistence farming. However, the *de facto* biodiversity remaining *in situ* could extinct due to economic and technological development that creates higher *economic return* from farming of new genetic materials. Therefore, economic incentive is required to conserve these genetic diversities in the same community, a criteria suggested by Pascual *et al.* [33] and UNEP [31]. The theoretical model developed in this study can be applied to identify particular landraces that are prone to extinct from the community. It further identifies farmers in the community having a minimum cost of conservation for these particular landraces such that the conservation cost is minimized. As the model maximizes the farmers revenues, could ensure better livelihood of individuals in the community as well as help to minimize the cost of *in situ* conservation of biodiversity *on farm*.

7. Future Research and Issues

Although this is a simple model, the example of application shows that it can applied easily to identify the farmers and varieties that minimize the cost of conservation. Therefore, there is ample space to apply the model in field studies to optimize the conservation costs in conservation programs. However, the major problem in field application could be to obtain the reliable data because farmers can exaggerate the information to acquire more compensation from the authorities. To ensure the collection of accurate information, suitable approaches such as intensive data plot (IDP) approach [1] [44] could be employed.

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